Transverse single-spin asymmetries at mid-rapidity at $\sqrt{s}$=200 GeV in $p+p$ collisions

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Abstract. The PHENIX experiment at RHIC has measured transverse single-spin asymmetries of charged hadrons in 2002 and 2005 in $p+p$ collisions at $\sqrt{s} = 200$ GeV and rapidities $|\eta| < 0.35$. An extended square root formula has been calculated for the asymmetries in order to make use of the full acceptance of the detector. No evidence for finite values can be observed in this kinematical region.

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INTRODUCTION

Large single-spin asymmetries (SSA) have been observed in different high energy $p+p$ collisions in the past [1, 2], although they were expected to vanish in perturbative QCD calculations at large transverse momenta p_T. The spin structure of the nucleon includes a term called transversity distribution δq, which is different from the longitudinal quark distribution Δq because relativistic boosts and rotations do not commute. Transversity therefore probes the relativistic nature of the nucleon and can be determined from transversely polarized scattering processes

$$A_{TT} \propto (\delta q)^2, \qquad A_N \propto \delta q. \tag{1}$$

The analyzing power A_N poses a direct measure of transversity in combination with another chiral odd function. Proposed models include spin dependent fragmentation functions (Collins effect, [3]), asymmetries in the intrinsic transverse momentum distributions of partons (Sivers effect, [4]), and quark gluon field interference in higher twist calculations [5]. The last one might have a major impact in the investigated energy regime, especially at lower p_T.

MEASUREMENT AND ASYMMETRIES

The PHENIX experiment at Brookhaven's Relativistic Heavy Ion Collider (RHIC) has measured the analyzing power of charged hadrons and neutral pions in the first polarized p+p run 2001/02 and results have been published [6]. Within the polarized run in 2005, a short period was devoted to transverse polarization to estimate A_{TT} as a systematic uncertainty in A_{LL}. The integrated luminosity collected in a significantly shorter period is comparable to the first measurement (0.15 pb^{-1}) with roughly three times the beam polarization. Measurements include polarization up ($\uparrow$) and down ($\downarrow$) in different bunches of the same accelerator fill. Also, RHIC provides two polarized colliding beams. SSA are obtained by averaging over one of the two beams at a time.

Charged particles are tracked in the drift chambers in the PHENIX central arms, each covering 90^o in azimuthal angle φ and $-0.35 < \eta < 0.35$ in rapidity. In combination with the axial magnetic field the scattering angle ϑ, momentum p, and charge q are measured. Event quality is based on certain cuts including a global vertex cut and track quality. Conversion electrons and decay particles with short lifetimes are major background sources for unidentified charged hadrons and are removed by ring imaging Cherenkov information and track matching in the outer detector layers.

Single-spin asymmetries in the scattering frame lead to an azimuthal cosine modulation of the differential cross section in the laboratory frame. The yields N:

$$\begin{aligned} N_{l\uparrow} &\propto L_\uparrow \cdot \Delta\Omega_l \cdot E_l \cdot (1 + A_N \cdot P \cdot c_l), & N_{l\downarrow} &\propto L_\downarrow \cdot \Delta\Omega_l \cdot E_l \cdot (1 - A_N \cdot P \cdot c_l), \\ N_{r\uparrow} &\propto L_\uparrow \cdot \Delta\Omega_r \cdot E_r \cdot (1 - A_N \cdot P \cdot c_r), & N_{r\downarrow} &\propto L_\downarrow \cdot \Delta\Omega_r \cdot E_r \cdot (1 + A_N \cdot P \cdot c_r) \end{aligned} \tag{2}$$

are dependent on the luminosities $L_\uparrow$ and $L_\downarrow$, the acceptances $\Delta\Omega_l$ and $\Delta\Omega_r$ of the detector arms (l left and r right) and their corresponding efficiencies E_l and E_r, and the modulation arising from the analyzing power A_N in combination with the beam polarization P. The mean value c_l or c_r of the cosine modulation in the respective detector arm is also charge- and p_T-dependent. The symmetry of the detector with respect to the cosine modulation causes $c_l(q, p_T) \neq c_r(q, p_T)$.

In order to remove differences in efficiencies and relative luminosity from the asymmetries, an extended square root formula has been calculated from:

$$\frac{N_{l\uparrow} \cdot N_{r\uparrow}}{N_{l\downarrow} \cdot N_{r\downarrow}} = \frac{(1 + A_N \cdot P \cdot c_l) \cdot (1 - A_N \cdot P \cdot c_r)}{(1 - A_N \cdot P \cdot c_l) \cdot (1 + A_N \cdot P \cdot c_r)} \tag{3}$$

leading to:

$$\varepsilon = A_N \cdot P = \frac{(N_\uparrow^2 + N_\downarrow^2) \cdot (c_l + c_r) - \sqrt{(N_\uparrow^2 + N_\downarrow^2)^2 (c_l + c_r)^2 - 4 c_l c_r (N_\uparrow^2 - N_\downarrow^2)^2}}{2 c_l c_r (N_\uparrow^2 - N_\downarrow^2)}. \tag{4}$$

Here, $N_\uparrow^2 = N_{l\uparrow} \cdot N_{r\downarrow}$ and $N_\downarrow^2 = N_{l\downarrow} \cdot N_{r\uparrow}$.

RESULTS

The differential cross section has been measured in 2001/02 and results have been published in [6]. Comparison to next-to-leading order perturbative QCD calculations using CTEQ6M parton distributions [7] and Kniel-Kramer-Pötter fragmentation functions [8] show good agreement at $p_T > 2$ GeV/c. The description of the unpolarized scattering process is applicable and, therefore, provides a solid basis for spin dependent processes.

Results of the extended square root formula have been cross checked with simple asymmetries, i.e. asymmetries between detector arms with the same polarization direction and asymmetries between opposite polarization directions in a single detector arm.

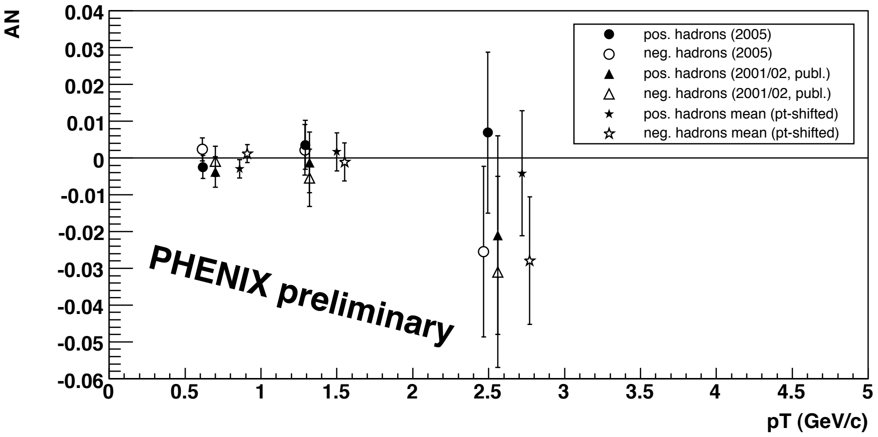

FIGURE 1. Results and statistical errors of the analyzing power A_N for charged hadrons from the year 2005 run compared to the already published data from 2001/02 [6]. Additional scaling uncertainties of 20% to 30% have to be included from the beam polarization.

For this purpose, the simple asymmetries have been cleaned of remaining efficiencies and relative luminosities, which themselves can lead to substantial false asymmetries.

Averaging over the polarization states of one beam at a time, two independent SSA can be determined, which have been compared for systematic deviations. While all results were found to be consistent with each other, their weighted means have been calculated.

Figure 1 shows the results of the analyzing power obtained with eq. 4 for charged hadrons and a comparison of the published results [6] with the new data set. New mean values have been calculated and are displayed p_T-shifted. For charged hadrons, no evidence of finite SSA can be observed in the considered p_T-range.

SUMMARY

The analyzing power A_N for charged hadrons has been measured at mid-rapidity and $\sqrt{s} = 200$ GeV in the PHENIX experiment. Due to improvements in accelerator performance, in 2005 the data set was doubled in a significantly shorter period compared to 2001/02. No evidence for finite single-spin asymmetries could be found in this kinematical region for transverse momenta $p_T < 5$ GeV/c so far.

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